Exploring the use of the OE-3 2021-01 pre-approved Authorized Limits to clear parts at the LBNL space effects testing facility

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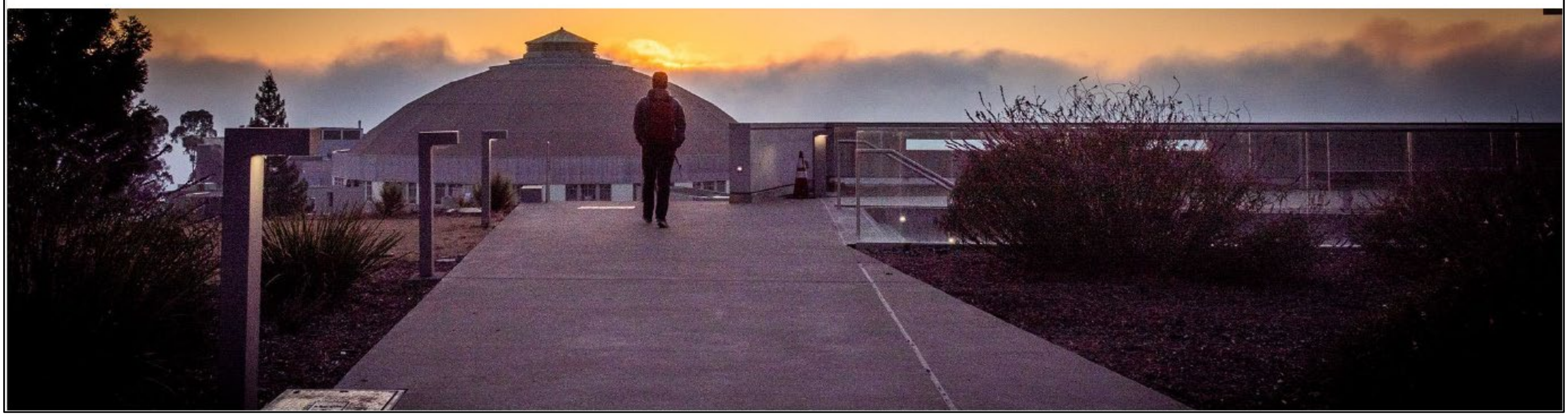
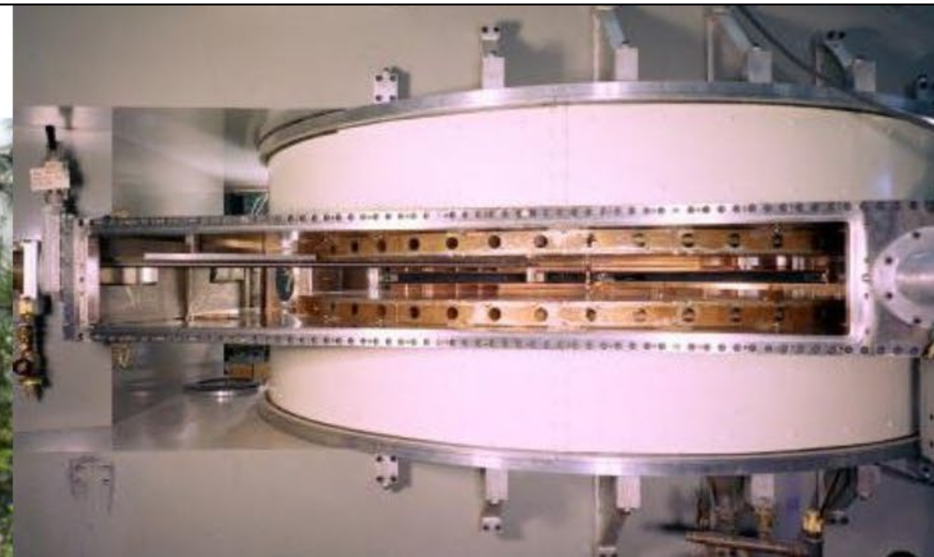


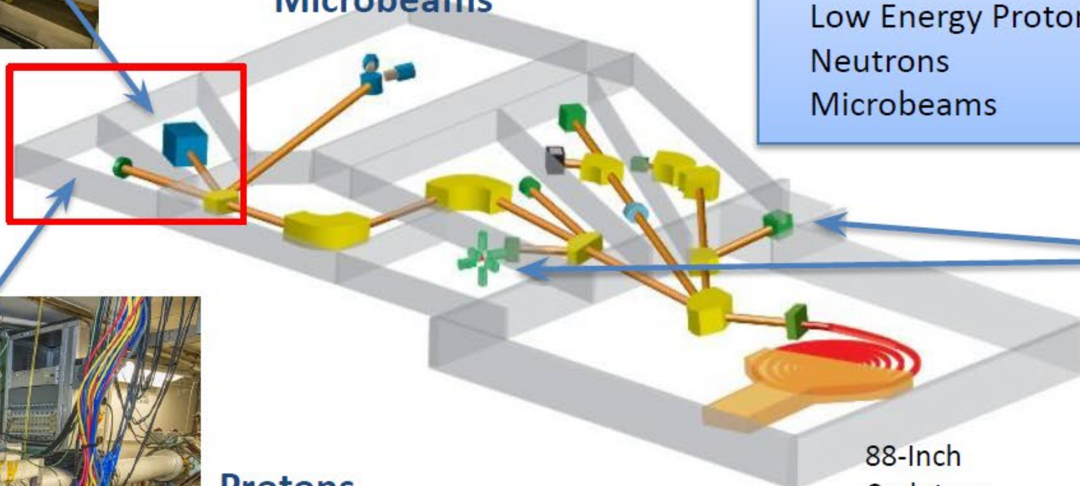
88-Inch Cyclotron



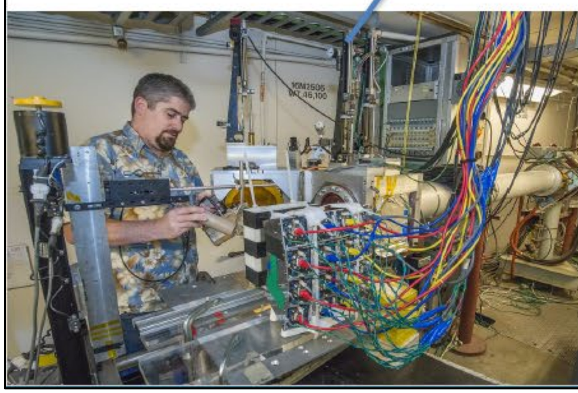
BASE Facility Layout & Capabilities

Heavy Ion "Cocktails"
(4.5 to 20 AMeV)
Low Energy Protons
(1 to 10 MeV)
Microbeams

"One-stop" facility for radiation effects testing
- Heavy Ions (in-air & vacuum)
- Light Ions
- Protons
- Low Energy Protons
- Neutrons
- Microbeams

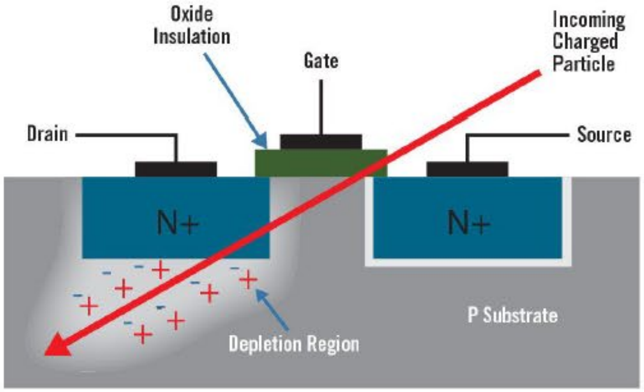


Neutrons
(8 to 30 MeV)



Protons
(10 to 60 MeV)
Light Ions
(30 to 32.5 MeV)

BASE Facility Mission

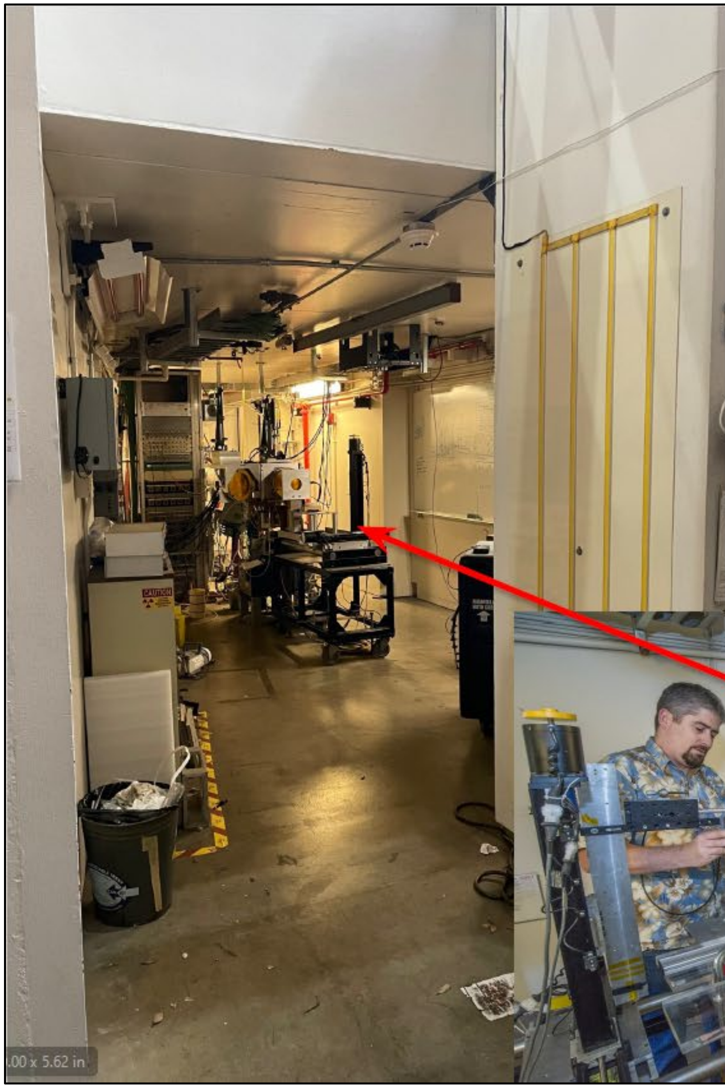


Support national security and other US space programs in the area of radiation effects testing.

Single-Event Effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic-particle strike.

Causes of SEE's: Galactic cosmic rays, solar particle events, particles trapped in planetary magnetic fields, natural isotopes in chip packaging, and nuclear weapons.

*Left: Recent images captured by NASA's **James Webb Space Telescope**. Right: **Artemis-1** on the launch pad. All of these had parts at the BASE Facility.*



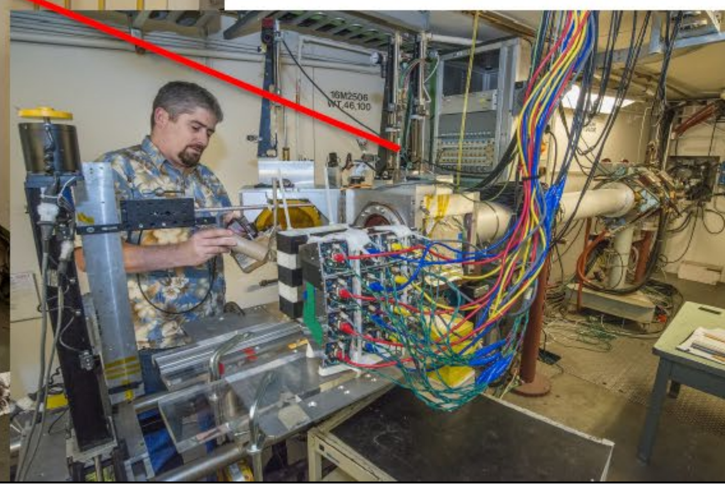
Caves 4A and 4B

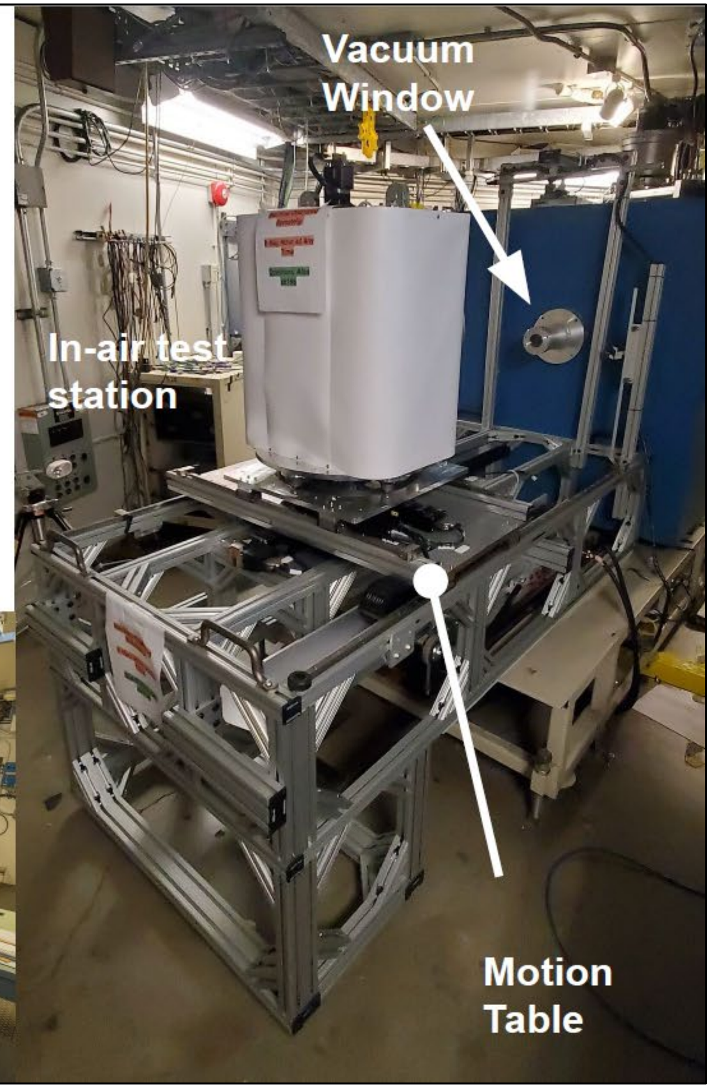
Heavy Ion “Cocktails”
(4.5 to 20 AMeV)

Low Energy Protons
(1 to 10 MeV)

Protons
(10 to 60 MeV)

Light Ions
(30 to 32.5 MeV)





FIRST REPORT OF INCIDENT

88-Inch Cyclotron Radiological Clearance Near Miss

September 24, 2021– B88 / 88-Inch Cyclotron

DESCRIPTION OF INCIDENT

Summary:

On September 24, 2021, external BASE facility users removed materials from B88 which had not been cleared for release from LBNL. The users removed the electronic parts, which could have been radiologically activated when tested in the heavy ion beam at B88, after RPG surveyed them, but prior to RPG issuing the clearance form authorizing the release. The users were aware of a 10 am radioactivity survey, but mistakenly assumed the results of that survey when they removed the parts.

RPG Radiological Control Technicians (RCTs) performed the radiological clearance surveys per the standard certification procedure. However, to expedite the process, they did not issue a radioactive materials label, a results-pending tag, or, as required for release, a clearance form (green tag). The users, who assumed the parts were cleared from radiological controls, removed potentially activated parts from bldg. 88. At ~2pm on September 24, B88 staff identified that the parts had been removed without approval. At ~3pm the clearance surveys were finalized and the results indicated that the parts met the clearance criteria and were not subject to radiological controls. At ~5pm, B88 staff ensured the return of the items to the Laboratory.

CONTRIBUTING FACTORS

What factors contributed to this incident occurring? What caused this incident?

Users assumed parts were not activated (contrary to training).

Insufficient communication (of clearance results) from RPG staff to B88 staff and users.

Inconsistent process for conveying clearance results: to enable timely clearances, RPG may provide verbal results before documentation.

B88 BASE Facility does not have a management system to identify parts that have been through the clearance process.

Recent RPG high staff turnover (>50% in field support) has significantly reduced the number of highly experienced staff fully qualified on the clearance process.

RPG oversight, field support and training for B88 are limited by resources. With one HP responsible for two operational zones which include the 88-Inch cyclotron at B88, the ALS accelerator and the medical cyclotron, and two RCTs supporting the zone that includes B88, staffing resources are notably reduced from historical levels.

RISKS AND MITIGATIONS

Identify Risks

Release of DOE radioactive materials into the public domain

Non-compliant shipment of radioactive materials.

Negative publicity for the Lab

Identify Current State

The items were returned to the Lab and subsequently cleared from radiological control using the standard RPG process, including a clearance tag and approved survey documentation.

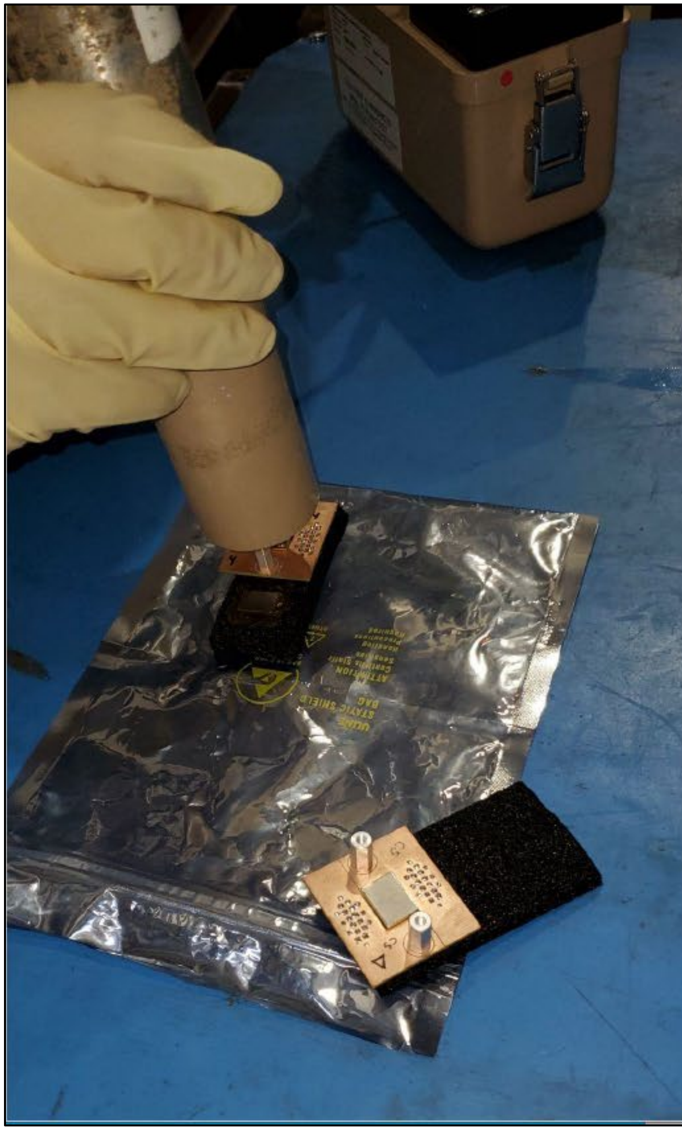
Mitigations

EHS: Consistently use the standard RPG clearance process.

NSD: 1) Stand down the BASE Facility for briefing and retraining.

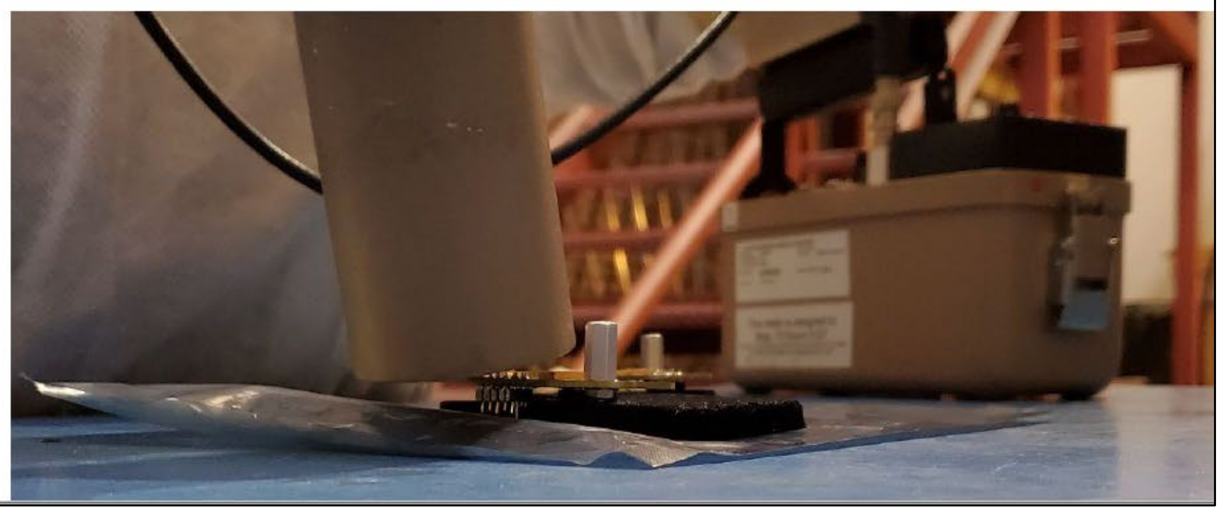
2) Establish a post-irradiation parts management process to ensure cleared and non-cleared parts are clearly identified and spatially separated. (We note that this is not a substitute for RPG survey certification.)

Both NSD and EHS: Improve communications with respect to radiation surveys and radiation worker responsibilities.



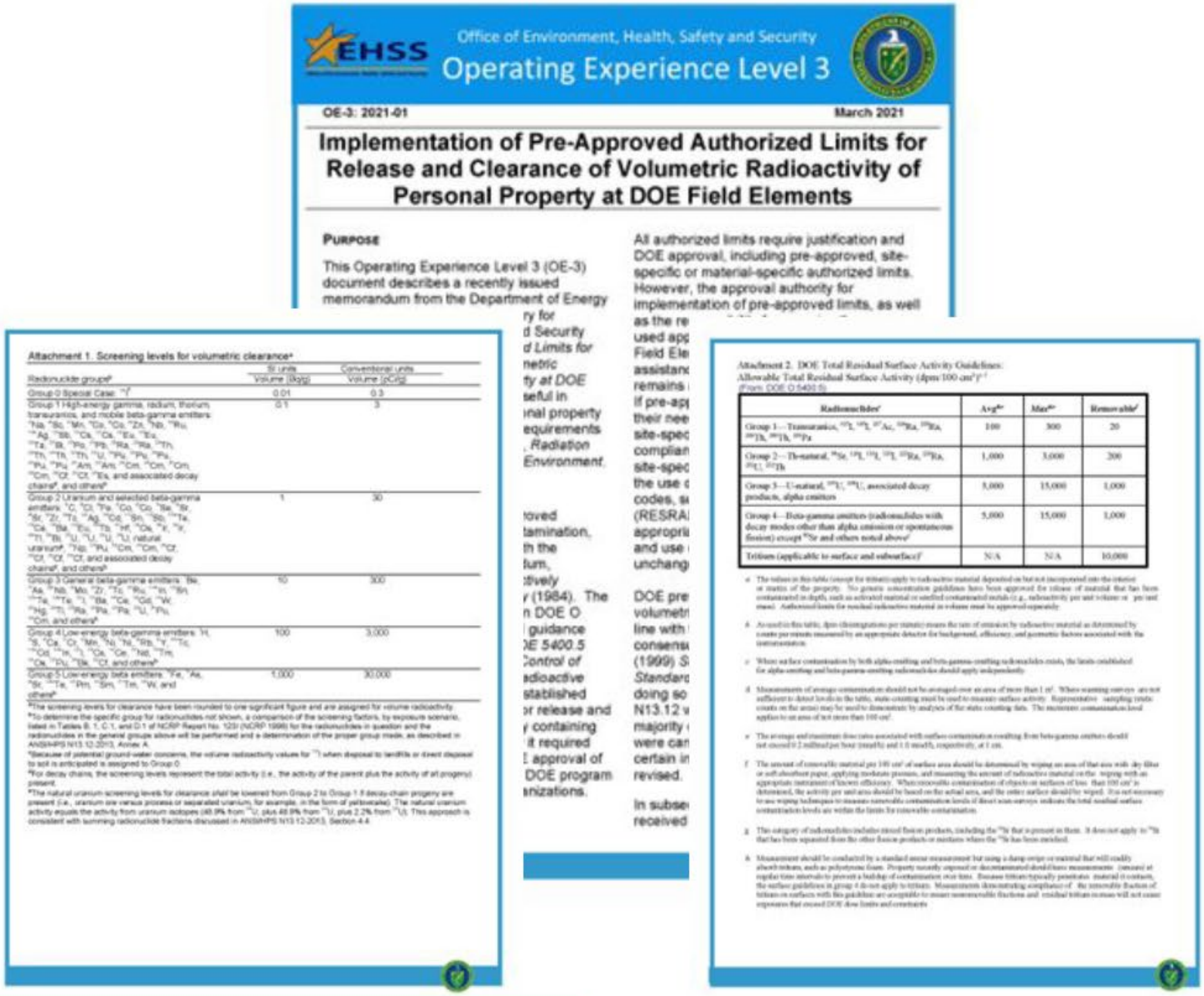
Radiological Release and Clearance

- Governed by DOE Order 458.1
- DOE approves local implementation through a Release and Clearance Plan
- Clearances must be performed in accordance with this Plan & implementing procedures



Volumetric Release and Clearance at LBNL

- Incorporates the 3-tiered clearance hierarchy from DOE-STD-6004-2016
  - Tier 1: Residual radioactivity has been demonstrated to be indistinguishable from background (IFB) at a level lower than the preapproved volumetric and surface contamination limits.
  - Tier 2: Residual radioactivity is greater than IFB, but less than the preapproved volumetric and surface contamination limits. **Scenario-specific qualitative ALARA analysis and management approval are required for Tier 2 clearances**.
  - Tier 3: Residual radioactivity is greater than the preapproved volumetric and surface contamination limits. DOE-approved specific authorized limits are required for Tier 3 clearances.
- Documents statistically based IFB process using MARSAME approach for Tier 1
- Discusses ANSI N13:12-2013 screening levels for Tier 2
- Incorporates the revised TBD approach for Tier 2
- Incorporates the March 2021 OE-3 pre-approved limits for Tier 2



EHSS Office of Environment, Health, Safety and Security
Operating Experience Level 3
OE-3: 2021-01 March 2021

Implementation of Pre-Approved Authorized Limits for Release and Clearance of Volumetric Radioactivity of Personal Property at DOE Field Elements

PURPOSE

This Operating Experience Level 3 (OE-3) document describes a recently issued memorandum from the Department of Energy

All authorized limits require justification and DOE approval, including pre-approved, site-specific or material-specific authorized limits. However, the approval authority for implementation of pre-approved limits, as well

Attachment 1. Screening levels for volumetric clearance

Attachment 2. DOE Total Residual Surface Activity Guidelines: Allowable Total Residual Surface Activity (dpm/100 cm²)

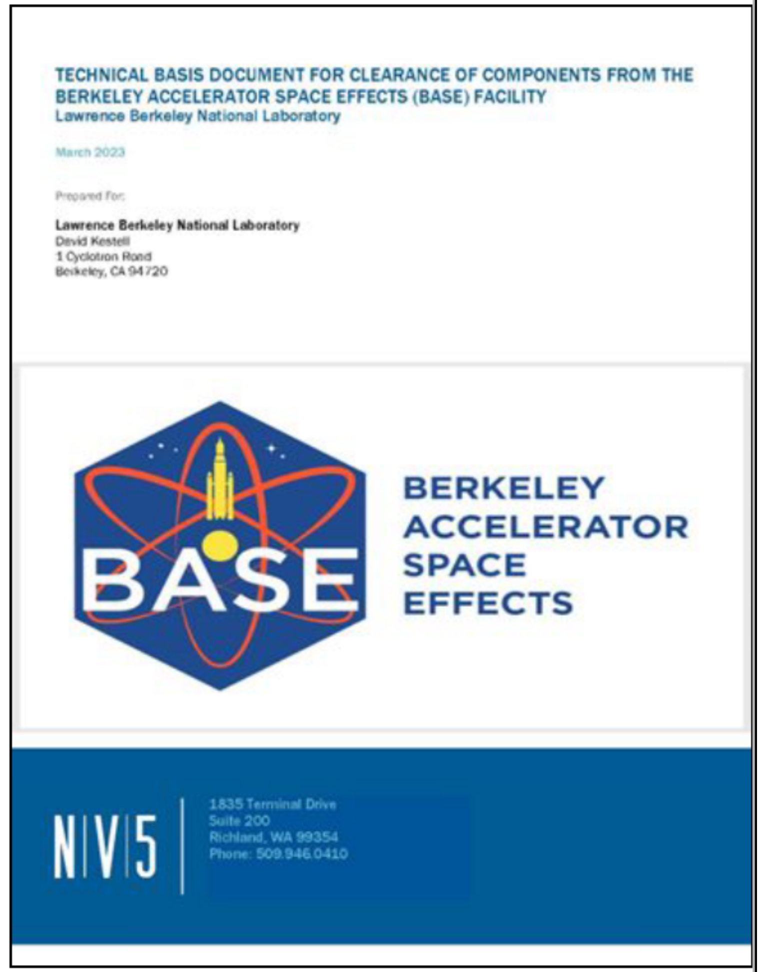
DOE OE-3 Pre-approved Authorized Limits

- Attachment 1 are the new pre-approved limits for volumetric contamination.
- Taken from ANSI N13:12 Table 1
- Applies to personal property only (i.e. no soil)
- Originally pre-approved for use by SC labs in 2016 following the issuance of DOE-STD-6004-2016
- Omitted a handy footnote from the ANSI, which stated that regulatory agencies may increase screening levels by one order of magnitude for bulk quantities of less than 1 metric ton

BASE TBD Development

Comprehensive evaluation of:

- Ions (21 in total),
- Energy (4.5 MeV to 20 MeV per nucleon and protons up to 60 MeV),
- Irradiation duration (seconds to mins)
- Materials that ions interact with
- Modeling to develop list of radionuclides of concern (ROCs)
- Identifying hard to detect (HDT) and easy to detect (EDT) isotopes
- Determining if there is a consistent ratio between HDT and EDT that can be leveraged
- Identifying the instruments and specifying the measurement methods for clearance survey



TECHNICAL BASIS DOCUMENT FOR CLEARANCE OF COMPONENTS FROM THE BERKELEY ACCELERATOR SPACE EFFECTS (BASE) FACILITY
Lawrence Berkeley National Laboratory

March 2023

Prepared For:

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BERKELEY ACCELERATOR SPACE EFFECTS

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Modeling

FLUKA

The BASE Facility provided the default operational assumptions

- Beam diameter of 4 inches.
- Maximum duration of 1 hour of irradiation on any individual part.
- Beam flux of 1E6 ions/sec/cm^2 and beam current of 81E6 ions/sec (13 particle pA).
- List of ions and MeV per nucleon, charge state, and LET.
- Post-generation decay times of 1 hour, 1 day, and 7 days.

–	Cocktail (AMeV)	Energy (MeV)	Z	A	Chg. State	LET (Entrance) (MeV/mg/cm²)	LET (Bragg) (MeV/mg/cm²)	Range (Bragg) Vacuum (µm)	Range (Bragg) Window/Air (µm)	Range (Max Vacuum (µm
B	4.5	44.90	5	10	+2	1.65				78.5
N	4.5	67.44	7	15	+3	3.08				67.8
Ne	4.5	89.95	10	20	+4	5.77				53.1
Si	4.5	139.61	14	29	+6	9.28				52.4
Ar	4.5	180.00	18	40	+8	14.32				48.3
V	4.5	221.00	23	51	+10	21.68				42.5
Cu	4.5	301.79	29	63	+13	29.33				45.6
Kr	4.5	378.11	36	86	+17	39.25				42.4
Y	4.5	409.58	39	89	+18	45.58				45.8
Ag*	4.5	499.50	47	109	+22	58.18				46.3
Xe	4.5	602.90	54	136	+27	68.84				48.3
Tb	4.5	724.17	65	159	+32	77.52				52.4
Ta	4.5	805.02	73	181	+36	87.15				53.0
Bi*	4.5	904.16	83	209	+41	99.74				52.9
B	10	108.01	5	11	+3	0.89	4.19	307.0		305.7
O	10	183.47	8	18	+5	2.19	7.16	239.2		226.4
Ne	10	216.28	10	22	+6	3.49	8.95	174.1		174.6
Si	10	291.77	14	29	+8	6.09	13.99	134.2		141.7
Ar	10	400.00	18	40	+11	9.74	18.65	11		130.1
V	10	508.27	23	51	+14	14.59	25.59	9		113.4
Cu	10	659.19	29	65	+18	21.17	33.95	8		108.0
Kr	10	885.59	36	86	+24	30.86	40.91	8		109.9
Y	10	928.49	39	89	+25	34.73	47.42	6		102.2
Ag*	10	1089.42	47	107	+29	48.15	59.27	5		90.0
Xe	10	1232.55	54	124	+34	58.78	69.24	4		90.0
Au*	10	1955.87	79	197	+54	85.76	94.18	5		105.9
He*	16	43.46	2	3	+1	0.11	1.45	836.0	795.5	1020.0
N	16	233.75	7	14	+5	1.16	6.04	503.0	464.0	505.9
O	16	277.33	8	17	+6	1.54	7.15	478.5	439.3	462.4
Ne	16	321.00	10	20	+7	2.39	8.95	337.5	299.2	347.9
Si	16	452.10	14	29	+10	4.56	13.99	269.5	230.7	274.3
Cl	16	539.51	17	35	+12	6.61	17.35	219.6	180.1	233.6
Ar	16	642.36	18	40	+14	7.27	18.65	242.2	203.1	255.6
V	16	832.84	23	51	+18	10.90	25.59	206.3	167.6	225.8
Cu	16	1007.34	29	63	+22	16.53	33.95	166.5	127.6	190.3
Kr	16	1225.54	36	78	+27	24.98	40.91	136.1	97	165.4
Xe*	16	1954.71	54	124	+43	49.29	69.24	105.4	66	147.9
O	20	374.89	8	18	+7	1.28				
Ne	20	440.56	10	20	+8	1.85				
Al	20	510.89	13	27	+10	3.50				
Cl	20	730.57	17	37	+14	5.61				
Ca**	20	905.53	20	44	+17	7.33				
V**	20	976.69	23	51	+19	9.88				
Cu	20	1260.99	29	63	+24	14.53				
Kr	20	1487.67	36	78	+29	22.26				
Ag*	20	2062.70	47	107	+40	35.29				
Xe*	20	2354.00	54	124	+46	45.22				
H+	10						Proton cocktail in vacuum (maximum energy)			
H+	60						Proton cocktail in Air (maximum energy)			

Modeling

Radionuclides of Concern

All 49 ion/energy combinations were modeled in FLUKA

- Any isotope with an activity equal to or greater than 0.1 pCi/g upon completion of irradiation is identified in the TBD.
- 4.5 MeV/nucleon Bismuth did not produce any isotopes.
- 4.5 MeV/nucleon Tantalum had the fewest isotopes produced (4 total).
- 20 MeV/nucleon Xenon had the most isotopes produced (1748 different isotopes).

All beam combinations reported in its own Excel table as an attachment to the TBD

Many have half-lives from a few seconds to a few minutes, so activity at specified post-irradiation times were modeled

- Post-generation decay times of 0, 0.1, 0.5, 1, 2, 4, 24, and 168 hours modeled

Modeling - validation

Modeling results were compared to gamma-ray spectroscopy results for actual irradiated sample.

- The model predicted the isotopes that were identified in the gamma-ray spectroscopy report
- The model conservatively overestimated the total activity that would be produced

This demonstrates that the model predictions can be used as process knowledge for the clearance process.

Materials

Image from Google Images
https://www.researchgate.net/figure/A-field-programmable-gate-array-FPGA-in-a-development-kit-for-programming-and_fig3_329228845

A Field Programmable Gate Array (FPGA) was used to identify materials commonly found in integrated circuits. FPGAs are composed of:

- Silicon die (silicon)
- Solder (tin and lead)
- Die underfill (i.e. phenolic resin, mostly carbon)
- Substrate (copper, nickel, gold, lead, tin, silicon)
- Capacitors (ceramic, electrodes, plating)
- Heat sink (copper and nickel)
- Heat sink adhesive (aluminum dioxide, zinc oxide, organic silicon)

The elements that make up each of these materials were included in the activation model.

Results

Process knowledge versus survey

With the modeling results, we can perform Tier 2 clearances (i.e. residual radioactivity is below pre-approved limits) based on the known Sum-Of-Fraction (SOF) at specified times.

For example, a chip/board irradiated with 4.5 MeV Boron will decay such that the SOF at 17-hours will be less than 1.

4.5 MeV Bismuth irradiation does not produce any activation.

Table 9. Hold Time to Reach an SOF of less than 1

Ion	Cocktail (AMeV)	Minimum Hold Time (h) (SOF <1for SL)
B	**4.5**	17
N	**4.5**	10
Ne	**4.5**	17
Si	**4.5**	17
Ar	**4.5**	16
V	**4.5**	19
Cu	**4.5**	29
Kr	**4.5**	14
Y	**4.5**	11
Ag	**4.5**	10
Xe	**4.5**	8
Tb	**4.5**	4
Ta	**4.5**	0.1
Bi	**4.5**	NA[(1)]

Technical Basis Document - challenges

- ✓ Assigning screening levels to isotopes not included in the ANSI standard
- ✓ Easy to Detect (ETD) surrogates for Hard to Detect (HTD) isotopes
- ✓ Modeling instrument response and calculating efficiency
- ✓ Adjusting for small size and mass of chips

SL - Challenges

Assigning Screening Levels (SL)

This became one of the largest challenges to the process

- ANSI N13.12 Table 1 (OE-3 list) only specifically identifies 129 isotopes
- To determine the SL for additional isotopes one must follow the directions in ANSI N13.12-2013 Annex A, which uses Tables B. 1, C.1, and D.1 of NCRP Report No. 123I (NCRP 1996).
  - Table B.1 is for isotopes in an air distribution model
  - Table C.1 is for isotopes in a water distribution model
  - Tabel D.1 is for isotopes that present an external dose due to direct exposure from the isotope buried in the ground.

Activated integrated circuits do not present an air or water dispersion concern, so Table D.1 was used to determine the appropriate screening level.

SL - Challenges

Initial Attempt Assigning Screening Levels (SL) - Continued

Condition	Assignment of SL
Isotope listed in Table 1 of the ANSI standard	SL assigned as shown in the table
Isotope has a numerical value listed in NCRP 123i, Table D.1 (Direct) and has measurable(1) photon emissions	Assigned a SL of 3
Isotope is not listed with a numerical value in NCRP 123I, Table D.1 and has measurable photon emissions	Assigned a SL of 30
Isotope is a pure, high-energy(2) beta emitter and has limited or minimal photon emissions	Assigned a SL of 300
Isotope is a low energy beta emitter and has minimal photon emissions	Assigned a SL of 3000
All other isotopes	Assigned a SL of 3 for conservative purposes

(1) Measurable photon emissions are those greater than 60 keV and greater than 10% intensity. 60 keV is considered the practical cutoff for detection by the Ludlum 44-2 probe.

(2) High energy beta is a beta, or electron, greater than 100 keV.

SL - Challenges

Impact of Assigning Screening Levels (SL)

- Potentially unnecessary long hold times when using easy conservative assumptions
- Making the effort to follow the NCRP 123I process for each isotope that presents a significant contribution to the overall source term may pay dividends in shortened hold times.

ETD/HDT - Challenges

Easy to Detect (ETD) versus Hard to Detect (HTD) Isotopes

With over 1700 isotopes in a single chip, we approached this problem by first sorting the isotopes by the assigned SL and then by total activity. Isotopes with an SL of 3, 30, and 300 pCi/g are easy to detect. Isotopes with an SL of 3,000 and 30,000 are hard to detect.

Initially we compared the SOF for the top 60 ETD isotopes with the highest activity compared to the top 60 HDT isotopes and we compared these at time 0-hours and 24-hours post irradiation. For example 20 MeV Vanadium.

- 0-hour has an 85:1 ratio ETD to HDT
- 24-hours has a 33:1 ratio ETD to HDT

ETD/HDT - Challenges

Easy to Detect (ETD) versus Hard to Detect (HTD) Isotopes (Continued)

- For conservatism we then placed those isotopes with an SL of 3 and 30 in the ETD group and 300, 3000, and 30,000 in the HTD group.
- The output for each beam type and each post irradiation time was evaluated.
- In all cases, the SOF of fraction ratio exceeded 10:1 ETD to HTD

Conclusion – Surveying for the ETDs will always ensure that the total SOF for combined ETD and HTD is less than unity if the ETD is less than unity.

Instrument Modeling - Challenges

Instruments

- The ETD all emit sufficient gamma to allow use of a Ludlum 44-2 1"x1" NaI detector
- Modeled the response using MCNP
- Source term was analytical data from irradiated chips that were analyzed using gamma-ray spectroscopy and also surveyed with the 44-2 probe

Instrument efficiency determined to be ~3% to 8%, depending on size of chip

Achieving an MDC less than the most restrictive SL of 3 pCi/g

- Difficult due to low mass of individual chips (typically <10g) or circuit boards (typically 80g)
- Evaluated various count times (Bkg and sample) and background cpm
- Aggregate samples to ensure mass >250g ensures MDC <3pCi/g in all conceivable counting situations.

Instrument Modeling - Challenges

Validation

Modeling results were compared to gamma-ray spectroscopy results for actual irradiated samples.

- The model predicted the isotopes that were identified in the gamma-ray spectroscopy report
- The model conservatively overestimated the total activity that would be produced

This demonstrates that the model predictions can be used as process knowledge for the clearance process.

Next Steps

- Evaluate nearly 2000 isotopes and assign an SL based on the primary emission and comparing to surrogate isotope using NCRP 123I
- Revise TBD Hold Times using the selected screening levels
- Submit finalized Technical Basis Document for Field Element Approval.
- Once approved, develop implementing procedures and work authorizations to allow for clearance of irradiated chips/boards after specified hold times.
- Require confirmatory surveys by RCTs in the beginning.
- Require periodic assurance surveys and oversight to validate continued use of approved process

Final Steps

Submit Finalized TBD for Field Element Office Approval

We plan to have a finalized TBD completed by end of this FY

Once finalized, we will submit to the Berkeley Site Office (BSO) for review and request concurrence.

Once approved, we will incorporate this TBD into implementing procedures and work authorizations to allow for clearance of irradiated chips/boards after specified hold times.

Will require confirmatory surveys by RCTs in the beginning.

Questions
?